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ABSTRACT

This is the Fourth Annual Report of the National Science Board (NSB). In this report, the NSB considers how science and engineering, through technology, can be brought to focus more effectively on societal problems. The Report reflects the conviction that changes in emphasis in the requirements for technology and changes in the pattern of demands for technological talent provide a strong basis for major Federal initiatives. Included in the document are recommendations related to policy in support of technology and policy for technology in support of society. Five major recommendations are discussed in detail in the report. (RH)

The Role of Engineers and Scientists in a National Policy For Technology

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REPORT OF THE NATIONAL SCIENCE BOARD

NATIONAL SCIENCE BOARD
NATIONAL SCIENCE FOUNDATION
1972

My colleagues in the Congress, America can be her true self only when she is engaged in a great enterprise.

To build a full generation of peace is a great enterprise.

To help the poor and feed the hungry, to provide better health and housing and education, to clean up the environment, to bring new dignity and security to the aging, to guarantee equal opportunity for every American — all these are great enterprises.

To build the strong economy that makes all these possible — to meet the new challenges of peace, to move to a new prosperity without war and without inflation — this truly is a great enterprise, worthy of our sacrifice, worthy of our cooperation and worthy of the greatness of a great people.

President Richard M. Nixon
Before a Joint Session of the Congress,
September 9, 1971

LETTER OF TRANSMITTAL

January 31, 1972

My Dear Mr. President:

I have the honor of transmitting to you, and through you to the Congress, the Fourth Annual Report of the National Science Board in accordance with Section 4(g) of the National Science Foundation Act as amended by Public Law 90-407.

In this Report, the National Science Board carries forward an exploration of one of the most important questions of our time: how science and engineering, through technology, may be brought to bear more effectively on societal problems. The Report reflects the conviction also that changes in emphasis in the requirements for technology, and changes in the pattern of demands for technological talent, provide a strong basis for major Federal initiatives.

There is a need for the strengthening and updating of American industrial technology for the purpose, among others, of reinforcing the national economic base upon which our efforts to deal with societal problems must rest. A parallel need exists in respect to technologies in the public service sector in order to heighten performance in functions indispensable in the everyday life of our communities.

Beyond these findings of action there is now an exciting new capability for the direct use of advanced methods and instruments of technology in seeking solutions to major problems confronting our people. New kinds of institutions are required to gain the full benefit of the Nation's intellectual resources in science and engineering for these enterprises.

Making the most of this new capability, and meeting the needs we cite, are hard tasks calling for new departures in Federal executive and legislative action. The National Science Board is confident that making the required effort will bring commensurate reward.

Respectfully yours,

H. E. Carter

H. E. Carter
Chairman, National Science Board

The Honorable
The President of the United States

ACKNOWLEDGEMENTS

The National Science Board has been greatly aided by the many contributions of members of the engineering, scientific, educational, and industrial communities in the discussions which culminated in this, its fourth report to the Congress.

The Board is especially grateful to the members of the Advisory Committee for Engineering of the National Science Foundation which met four times to discuss the report and which in addition spent a great deal of time offering specific language and reviewing text. These are:

Dr. Lynn S. Beedle, Director, Fritz Engineering Laboratory, Lehigh University;

Dr. Donald A. Dahlstrom, Vice President for Research and Development, Envirotech Corporation, Salt Lake City, Utah;

Dr. Daniel C. Drucker, Dean, College of Engineering, University of Illinois;

Dr. Harry C. Gatos, Professor of Metallurgy and Materials Science, Massachusetts Institute of Technology;

Dr. Arthur E. Humphrey, Director and Professor, School of Chemical Engineering, University of Pennsylvania;

Dr. William K. Linvill, Chairman, Institute of Engineering Economic Systems, Stanford University;

Dr. Rustum Roy, Director, Materials Research Laboratory, The Pennsylvania State University;

Dr. Robert E. Uhrig, Dean, College of Engineering, University of Florida;

Dr. M. E. Van Valkenburg, Professor and Chairman, Department of Electrical Engineering, Princeton University;

Dr. Max L. Williams, Jr., Dean, College of Engineering, University of Utah.

The industrial viewpoint was effectively presented by the following distinguished persons who advised the Board on the future role of science and engineering in the Nation's industries:

Dr. Robert W. Cairns, Deputy Assistant Secretary for Science and Technology, Department of Commerce (former Vice President, Hercules, Inc., Wilmington, Delaware);

Dr. Thomas C. Kavanagh, Vice President, Praeger Kavanagh Waterbury, New York, New York;

Dr. J. Ross Macdonald, Vice President of Corporate Research and Engineering and Director, Central Research Laboratory, Texas Instruments, Inc., Dallas, Texas.

Officials in those Federal departments and agencies with mission roles which benefit from or support engineering and technology have reviewed this report and have made many valuable contributions.

Finally, the Board is deeply indebted to the "Writing Group" composed of Dr. John M. Ide, Mr. Frederic W. Collins, and Dr. Michael Modell. This group did all the major writing and spent endless hours in drafting original text and incorporating recommendations from members of the Board and from consultants. The Board is also grateful to the staff of the Board Office who have provided administrative and secretarial assistance throughout the entire process of preparation of this report.

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INTRODUCTION

AND SUMMARY OF RECOMMENDATIONS

For three decades the Nation has maintained a strong commitment to the technologies of war and defense. In the Sixties a second major commitment was made to the technologies of space. On both we have concentrated in massive ways the talents, energies, and physical and economic resources that have been required.

The Nation now needs an equally strong commitment to the technologies of peace, suffused with a sense of national purpose. We confront a variety of complex problems throughout the American society. We must broaden and intensify our efforts to deal with them. This is opportunity as well as need. We believe there is now a bright promise that American scientists and engineers can indeed help to meet our material and social requirements and help to solve major societal problems.

New circumstances make possible a different marshaling of knowledge, thought, and energies in science and engineering. To convert that potential into reality, and to move effectively toward the national commitment we seek, two major changes are required:

First, the principle must be accepted that the Federal Government has a new role and responsibility with respect to American industrial technology. It must undertake as a conscious mission the stimulation and support of research and, where desirable, development in order to promote continuing technological health. As a balance for that stimulus, it must provide adequate means of technological assessment.

Second, there must be designed and created institutional mechanisms to deal with societal problems in their complex entirety instead of piece by piece in traditional ways. Major efforts so organized must be coupled with existing governmental and private capabilities, both to enlarge and to focus the contributions of American science and engineering toward finding solutions for major problems.

We have developed a series of recommendations to suggest the ways in which these two fundamental changes can be achieved.

Their attainment will be difficult, and the efforts will be costly. Progress must rely on team efforts joining science and engineering with other professions and other fields of knowledge, in industry, the universities, and government. In carrying out a new mission, the Federal Government will face hard choices on priorities and detailed objectives, and progress will depend on the society's collective wisdom expressed through its processes of government.

The recommendations mark out one approach, not the only possible approach, toward meeting the needs in the area of technology discussed herein. This approach is subject to further evaluation, along with any alternatives, in the light of pertinent developments in policy or possible changes in the Federal organizational structure or reassignment of missions affecting technology.

The propositions stated are large. Yet on both the domestic and international scene we see no realistic alternatives. In a society as large and technologically advanced and complex as ours, there is a circle which cannot be broken. The improvement of our technology through broadened and intensified research and development is needed for continuous strengthening of the economic base. This in turn is essential if we are to meet the prospectively extraordinary costs of solving the complex problems of the American society.

The principal missions of the National Science Foundation (NSF) are to support basic scientific research and programs in education to strengthen scientific research potential. To this has been added more recently the mission of supporting a combination of basic and applied research on major national problems, and in pursuance of this mission NSF has launched a program called Research Applied to National Needs (RANN). Accordingly, Foundation programs embrace the entire science-engineering-technology-society sequence through which new scientific understanding is translated via engineering and technology into products and services for the uses of society.

This report deals with the role of engineers and scientists within a changing national policy wherein technology is reoriented from military application toward greater effectiveness in meeting the needs and aspirations of American society.

In the development of our theme, and the formulation of the recommendations which are summarized below, certain considerations are of first importance.

During the long interval in which so much of our national effort has been commandeered to meet threats and challenges from outside, parts of our technology became hardened in forms inappropriate to the domestic economy. In the same interval there was insufficient opportunity to realize the tremendous potential of science and engineering for innovative contributions to the national well-being. The present need is to achieve flexibility and growth in all parts of our technology so as to realize its potential for social benefit.

Technology has flourished because it is recognized as a foundation of our economy and of the well-being of our people by performance going back to our very beginnings. Its preeminence is attributable in part to the demands which were imposed by the tasks of developing a continent. Technological change is built into our national habit pattern. A continuous stream of new developments nourishes our economic health and growth and helps support our international economic position.

Yet, this progress has faltered. The economic strength of certain industries, particularly long established, basic industries, has diminished in domestic and foreign markets partly because of lagging effort in research and development. In turn, this reflects, inter alia, neglect by executive managers; the enticement of bright young minds to fields of greater glamor; shrinkage of profit margins from which both support of research and the wherewithal for installing expensive new technologies are drawn; adverse economic developments, including factors leading to intensification of foreign competition; and expedient decisions to buy technology abroad.

Ahead lies the possibility that technologically alert industries may drift into premature aging for the same reasons, or from overconfidence, absence of close competition, or retrenchment during economic downswings. Already in prospect is a diminution in the technological dividends from the large Government defense and space programs, which have provided some industries with ready-made research and development.

An additional phenomenon also accounts for the decreasing investment in research and development in some enterprises. As technology becomes more sophisticated and based more on theory and general principles, the results of research tend to become more generic. Since this reduces the competitive advantage accruing to

the entrepreneur, it has dampened the incentive of some to invest in research and development. Thus, the general social benefit of generic results provides the rationale for public funding of such research and development.

All of these considerations point to the emerging need of a new role for the Federal Government: a responsibility for substantially increased support and stimulus for research and development in many areas of the private economy.

The stimulus to technology which we advocate must be balanced by effective forms of credible public technological assessment. Society has reached a stage of such complexity, and the impact of technology is so great and so diverse, that new technology must be closely correlated with the strategies of a mixed society with neither pure *laissez-faire* nor rigid central direction. The means of assessment must not imperil the processes of healthy technological development. It will remain essential to balance innovation and restraint, economic opportunities and offsetting social costs, beneficial accomplishments and harmful side effects, to take advantage of the tremendous spontaneity of science and engineering as focused in technology while, recognizing the growing disinclination of society to be subject to unwelcome and unexpected consequences of new technological departures, preparing the public for desirable change. There is need for public determination of scientific and technological fact as free as possible of either the actuality or the imputation of advocacy — for competent assessment credible to the public and private entrepreneurial interests.

The evident interest of the public in some form of technological assessment reflects new orderings of values in our society. There is a tendency to regard these changes as imposing severe restraints upon scientists and engineers. There is an opposite view that the new order of values opens new horizons for the scientist and the engineer by bringing criteria of social desirability into better balance with economic constraints.

In advocating new Federal encouragement and support for technology, we recognize the necessity of maintaining at full strength support for basic and exploratory research in science and engineering. Federal programs in this field, notably those of the National Science Foundation, expand the vital "knowledge base," thus providing options for technological advance. Failure to maintain those programs would be partially to defeat the purpose of

augmented effort in support of research and development in technology.

Beyond the technology mentioned thus far, largely that generated in industry, there is a class of technological research which society needs but which is not pursued with sufficient vigor with only a market stimulus. Many of these technologies relate to the performance of public services. Fire protection, waste collection and disposal, and noise control are examples. The incidence of such needs typically is localized, but they add up to large national problems. Their financial cost represents, as well, an economic burden running into many billions of dollars in the national aggregate. These is no question that this burden can be significantly reduced by improving the technologies involved. Federal support for such progress is clearly appropriate, and both Federal and State efforts to help in aggregating markets and to effect broader and more rapid technology transfer are desirable.

An important aspect of our times is the rising awareness of the size and complexity of problems which have arisen in our society. Fortunately at this juncture there are emerging highly promising, sophisticated new methods for analyzing them, particularly systems analysis, computerization, and the mathematical simulation in "models" of the dynamics of complex problems. This combination — awakened perception of the boundaries of societal problems and the acquisition of means of their analysis — both urges and makes possible the devising of institutional arrangements, meriting description as "social inventions," to focus on the formulation of alternative solutions, and the planning of their implementation. If this is done, an immensely constructive step will have been taken in the analysis of complex problems in their entirety, going to causes rather than going at symptoms, searching for solutions with long range validity instead of settling for short term, palliative measures.

Consideration of the role of engineers and scientists in our society makes evident a signally important reality of contemporary life: the unremitting multiplication of technological considerations in the issues concerning which the public must make decisions. As the technological components of issues of public policy grow in number and complexity, public ability to evaluate alternative courses must necessarily be severely strained.

There exists, therefore, need for an effort to enhance the public's understanding of technology and its role in our society so that we may more adequately confront the issues on which sound public judgments have to be made. The Federal Government should assume the initiative in launching programs to provide that understanding.

The summary of recommendations follows:

SUMMARY OF RECOMMENDATIONS

Recommendation I. GOVERNMENT AID IN SUPPORT OF INDUSTRIAL TECHNOLOGY

Government policy should encourage the injection of basic and applied research activity into mature industries, and the maintenance of a high level of such activity in technologically advanced industries. Page 19.

Recommendation II. TECHNOLOGICAL SUPPORT FOR PUBLIC GOODS AND SERVICES

Key technologies essential to the attainment of societal goals, but not presently commercially viable, should be continually developed, strengthened, and renewed through Government-aided research and development. Page 24.

Recommendation III. EXPLORATION OF FUTURE ALTERNATIVES

There should be established, on a continuing basis, substantial groups of full-time professionals of outstanding competence to develop the capability (methodology and manpower) to explore specific large problems of national importance, and to explore alternatives for dealing with those problems. The groups would develop alternative exploratory approaches, lay out several possible trials, and devise appropriate experiments. So equipped the decision-making institutions of our country may better guide its future. Page 34.

Recommendation IV. PUBLIC UNDERSTANDING OF TECHNOLOGY

The National Science Foundation and the Office of Education should as a matter of long range concern seek to promote the

teaching of the principles and nature of technology at all levels of formal and informal education. The existing NSF program on Public Understanding of Science should undertake, within its existing field of responsibility, efforts to enhance public understanding of technology and how it differs from science. The Federal Government and industry should mount parallel efforts to convey that understanding through channels outside the classroom. Page 40.

Recommendation V. TECHNOLOGY ASSESSMENT

There should be formed in appropriate agencies, including the National Science Foundation, or as separate bodies if need so dictates, groups responsible for the long range analysis and assessment of technological systems of broad public importance. It is urgent that new capabilities be created to evaluate the societal benefits of new technological developments in advance of their wide scale dissemination and call attention to their potential hazards, undesirable by-products or side effects. Such groups should make generally available to the public information regarding comparative costs and values as a basis for decision-making in order that appropriate safeguards may be established. They could call upon all national advisory and research resources to provide the many diverse substantive skills required in assessment. Page 42.

PART I

POLICY IN SUPPORT OF TECHNOLOGY

In our society today, knowledge and discovery are attaining preeminent roles in the never-ending effort to better the human condition. Science, engineering, and technology are needed across a broadening front and in increasing measure if we are to achieve balanced growth. New discoveries in science are required to broaden the knowledge base. Strengthened and increasingly more versatile engineering is needed to extend this knowledge and apply it to human needs. Technology, the application of knowledge to practical purposes, continually guided and strengthened by research and development, must be built into our industries to keep them productive and competitive without wasting natural resources or destroying the environment, and must be adapted to new functions in meeting nonmaterial needs of society.

The discovery of new knowledge is primarily the function of science. No one can say from which of the sciences the next new transforming concepts will come. Progress in research must therefore be sustained across the board. Physics, chemistry, biology, astronomy, geology, and mathematics have enormously expanded our understanding of the world around us, from the fundamental nature of atoms and molecules to the kinds of matter and the transformations which occur in the universes surrounding us. Knowledge of the basic processes of life is rapidly expanding through exciting new successes in science, as witness those in molecular research. Knowledge of materials and how they may be put to use is increasing by dramatic steps exemplified by new understanding of the solid state, transistors, composites, and new alloys. The complexities of human behavior, including such fascinating mysteries as the learning process, are beginning to yield to systematic study.

Engineering is the bridge between science and society. New knowledge in the physical sciences and mathematics is translated through engineering into new products and services for mankind. Similar bridges with the biological and social sciences are now "under construction."

The work of engineers is, stated broadly, the translation of all available information into forms useful to man, which might mean a method, a process, a design, or a device or "object." Engineers are trained to be problem solvers, drawing upon whatever background is necessary to obtain an answer for the job in hand. This background includes scientific data and theories if they are available; and, when reliable data are insufficient, there is recourse to empirical correlations, hypotheses, approximations, and assumptions. Where more must be learned about basic phenomena to permit solution of the problem, engineers perform research.

Engineers are the keystone of our industrial structure, having the primary role in our society of generating and applying technology, and of innovating, and thereby sustaining the effectiveness of industry. They perform functions of planning and directing, research and development, design, production and operation, and consultation on technological matters. Their range of functions thus extends from basic research through production engineering to technical management. Engineers are largely responsible for the development of the technologies which have made American industry the most advanced in the world. The industrial greatness of this country rests heavily on engineering accomplishments.

Today, new engineering explorations bring new accomplishments. Biomedical engineering provides better replacement parts for human bodies. Holography is leading to sono-radiography for diagnosis. Enzyme engineering is making these unique catalysts more broadly applicable.

It is a fact of substantial importance in considering new roles for scientists and engineers that the overwhelming majority of engineers, four-fifths of them, and many applied scientists are employed in private industry, both manufacturing and nonmanufacturing. The actual number of scientists and engineers employed in industry exceeds one million. Engineers make up one of the very largest American professional communities. One of the meanings of this statistical reality is that a changing policy for technology must find acceptance and support among policy makers in the industrial sector where most of the engineers, and significant numbers of scientists, will no doubt continue to be found.

TECHNOLOGY

Technology is the science of the application of knowledge to practical purposes. Technology can be thought of as a tool, as a body of knowledge developed for a specific purpose, or as a methodology which can be brought to bear on a problem. A technical method of extracting petroleum from shale is technology, as is automated production of engine blocks, or the use of the basic oxygen process in making steel.

Each field of engineering has characteristic technologies it develops, explores and utilizes. In chemical engineering these include chemical transformations in the making of synthetics, polymers, and plastics; separation processes such as distillation; and the design of chemical plants, including automatic control. Civil engineering uses the technologies of building design and construction; and hydrology and hydrodynamics, involving the flow and fall of water, droughts, floods, and runoff.

Much of the promise of progress in technology grows out of the acquisition by today's scientists and engineers of powerful new tools, such as the systems approach and computers. Developed for use in strictly technological problems, they are proving to be increasingly more helpful as wider applications are explored, and perfected, and are being adapted to the study and analysis of at least some of today's socio-technological problems. Possessing what only quite recently seemed incredible capabilities in speed and in mastery of complexities, they have brought into the realm of the possible many tasks formerly regarded as impossible because of the time and aggregations of brain power required to achieve a successful result. The computer, properly employed, can help in any situation requiring analysis of complex interactions. Used as an auxiliary in the modeling of problems, it can provide insights into the consequences of an almost limitless variety of changes in cause-and-effect relationships within them.

Different fields of technology vary in the extent to which they utilize science. In the newer fields, such as aerospace, communications, integrated circuits and electronic industrial process control, technology is closely coupled to the basic sciences, and applicable new science is translated into engineering terms soon after it is generated. In some older fields, such as metal processing and building construction, the science-engineering relationship is

more remote, and new science enters into the technology, if at all, only with difficulty and after a lapse of time.

The requirement for science varies with differing technologies; and, inasmuch as technology predates science, clearly there was a long interval of human history when technology's base in science was minimal. From the earliest times, man has used observation and ingenuity to shape tools, make pottery, mine metals, and construct roads, bridges, and buildings. This was done, and on the whole done well, by trial and error, hypothesis and experiment, with no scientific idea why the materials behaved as they did. Metals were refined for use without the chemical knowledge that metal oxides were being reduced by the removal of oxygen. This kind of technology evolved through more advanced stages such as those embodied in the Industrial Revolution, the work of Samuel F. B. Morse, Thomas A. Edison, and Alexander Graham Bell, and indeed the "practical arts" characterizing some industries even today. But increased knowledge of science has brought increased infusions of that knowledge into technology, and at the very least may be said to have brought the trial and error process to a higher level of sophistication or a lower level of empiricism.

TECHNOLOGY AND INDUSTRY

Apart from actual requirements, industries vary widely in their individual attitudes toward science and technology. Some have been solidly science based from the outset. Their managements, often technically trained, have a keen perception of how tightly their fortunes are "skewered" to further scientific advances. Some industries, once science based, have as they matured lost contact with the results of recent research, have failed to innovate, and have become obsolescent. Some are content with relatively unsophisticated technology built up by experience and practical art. All are, or ought to be, important elements in the economic strength of the country. A few examples will illustrate.

Mineral extraction technology grew in sophistication as long as the mining industry both supported the associated research and development and continued to offer employment to engineers graduating from the mineral industries departments of engineering colleges. As this industry decreased its proportionate investment

in research and development, and as the greater interest in new sciences and technologies drew the bright technical minds away, the associated departments in the engineering colleges dried up, and the technology soon stagnated. The electric power industry has had a somewhat similar history, although it now enjoys some revival because of critical shortages and the environmental challenge. Of course, in both cases there has been competition from new, rapidly growing industries like aerospace and electronics, offering more glamorous careers to the graduating engineers.

The chemical, synthetic fibers, and petroleum industries, on the other hand, have succeeded better than power and mining in maintaining a reasonable balance between research and development and the other functions of the industry. Their technologies have become more sophisticated as the industries have matured.

Recent examples of new technologies closely associated with science are nuclear energy, transistors, integrated circuits, and lasers. These technologies are already the basis for the modern electronic industries, yet they were made possible only by advances in solid state physics within the last two to three decades. The time delay between the gain of new knowledge from physics and its development into major engineering technology suitable for industrial exploitation was only a few years. The work of the physicists and electrical engineers was also much closer in content to the resulting technology than was the case with earlier inventions.

Research and development, whether performed in universities or industrial laboratories, often lead to technologies of increased vigor. Much new technology results from the gradual accumulation of small gains in science, rather than from scientific breakthroughs on the scale of that which underlies the laser.

TECHNOLOGY AND THE FEDERAL GOVERNMENT

Within the last 30 years the Federal Government has become a major factor in the development and evolution of technologies, directly by funding of academic and industrial research and much development as well, and indirectly by building up the industries to produce vast quantities of material. For the past two decades, approximately one-half of the total industrial research and development spending has been funded by contracts from the Federal Government (see Appendix A). Major industries involved are

aircraft and missiles, electrical equipment and communication, chemicals, motor vehicles and other transportation equipment, and machinery. Total industrial research and development spending by Government and industry together had risen from about $4 billion in 1953 to an estimated $18.3 billion in 1971. The Government has underwritten this in order to carry out its own clearly defined missions and responsibilities for needed advances, particularly in space, defense, and atomic energy.

Another important contribution of the Federal Government to a new science-based, high technology industry is made when the Government exercises its role as the first and biggest customer of the new industry.

Among the Federal contributions, in addition to the evolution of some technologically advanced and sophisticated industries, such as computers, aircraft, and electronic instruments, have been spin-offs of major proportions. New technologies — ranging from semiconductor technology, integrated circuits, and advanced computer capabilities to improved communications and transport aircraft — have been widely applied in other industries.

These advanced technological industries are tomorrow's mature industries. In the process of maturing, a number of our earlier industries have underinvested or gradually reduced investment in technological research and development. The Nation should be forewarned not to let this deterioration affect currently maturing industries.

PROBLEMS OF MATURE INDUSTRIES

The mature industries in the United States (e.g., mineral extraction, primary metal processing, basic chemicals, paper, glass, machine tools, cement, brick, and building materials, construction, motor vehicles, and rail transportation) are the economic backbone of this country. Only if most of these industries continue to be successful can this Nation have a strong economy which, in turn, can sustain important societal programs.

If a mature industry turns stagnant for any one of several reasons, including a failure to remain strong in its research and development, it cannot contribute well to a strong economy.

In considering reasons for letdown in research and development, the general observation seems valid that, as technology becomes more sophisticated and based more on theory and general principles and less on empiricism, the results of research, and even of development, tend to be more generic and therefore less uniquely appropriable by the particular organization making the original investment. What this means is that the private returns of research and development tend to go down, even while the social returns of research and development are going up. As a result the incentives acting on the individual firm become weaker. Consequently, the more efficient and productive research becomes from the social point of view, the more individual firms will tend to underinvest in research because it benefits their competitors as much as themselves. This contributes to the rationale for public support of industrial research and development.

Research and development provides flexibility and leads to growth. It is a necessary step in the development of new technology, and of key importance in the innovative process leading to new products. A growing and more affluent population requires new technology and needs and wants new products of many kinds. The economic constraint on engineering design is still with us and will be a major factor for years ahead. A reconciliation of the need for improvement with acceptable cost must be made with respect to products for which demand exists throughout our society, including construction materials, automobiles, and home appliances. As one illustration, homes constructed with more effective built-in insulation would be more comfortable, quieter, cheaper to heat in winter and to air condition in summer, and generate less pollution from both heating and cooling.

Higher efficiency and productivity in our industries, which can be one dividend of research and development, can help to free a larger fraction of our total resources for the tasks of solving pressing societal problems. Only a productive and flourishing American industry can provide the strong tax base needed if the Government is to underwrite costly programs of social gain.

In response to new emphasis on "the quality of life," many products will have to be reengineered for improved durability, safety, and environmental "cleanliness." Because meeting these new criteria will mean added costs for the producer, conventional

products must be made more efficiently to provide offsetting economies.

Technological obsolescence in production is considered by some to be a factor in the decreasing economic viability of certain American industries in international markets, and in competition in domestic markets with products from abroad. Michael Boretsky of the Department of Commerce has classified the manufacturing industries as "nontechnology intensive" and "technology intensive," depending on the ratio of research and development to sales and the ratio of technological manpower to total employment.[1] These factors are more closely related to the rate of generation of technology than to the "intensity" of technology employed.

Trends in imports and exports within these categories are shown in Appendix B. Many of the mature industries — or, more accurately, industries employing mature technologies — fall within the nontechnology intensive classification (i.e., steel, textiles, paper, nonferrous metals). In many of these cases, there is much evidence to suggest that an infusion of basic and applied research and development could substantially improve the competitive position of these industries.

In some cases industries and their leaders have deliberately held down investment in research and development. Again, certain of the same mature industries would rather rely on trade barriers than have the Federal Government assume a greater role in the stimulation of their research and development. It is essential, however, for our national well-being that the Government and these industries, as a joint responsibility, take the proper steps to insure their continued technological growth. If first-class technical minds could be attracted to those industries which are a substantial component of our economy but are facing technological obsolescence, rewarding results could be confidently expected. Such minds will be attracted, as a minimum but not necessarily in itself a sufficient condition, only if research and development opportunities are increased.

It is recognized that technological advances alone are insufficient and that economic rearrangements and legal questions are involved as well.

[1] *Technology and International Trade*, Proceedings of the Symposium Sponsored by the National Academy of Engineering at the Sixth Autumn Meeting—October 14 and 15, 1970.

NEEDS OF ADVANCED INDUSTRIES

For much the same reasons as those applying to mature industries, we must also insure that the advanced technology industries, such as computers, aircraft, and electronic instruments, maintain their flexibility and growth potential.

Within recent decades, particularly since World War II, we have seen the development of those strongly science-based industries in which research (basic and applied) has been from the outset integrated into the organizational structure. These industries are characterized by the systematic development of applicable new technology from research, e.g., industries concerned with polymers and plastics, electronics and lasers, chemicals and synthetic textiles, aerospace and communications. By keeping very close to the pertinent science and by applying a large volume of resources in engineering manpower and facilities to their technological goals, these industries have achieved a veritable explosion of new products and materials. Thus a direct and immediate relationship between science and technology, deliberately introduced by these industries, has paid off heavily in economic growth and productivity. "Technology, as we now know, is the basis of increased productivity, and productivity has been the transforming fact of economic life in a way which no classical economist could imagine." [2]

Many of the advanced technological industries fall within the technology intensive category. The overall trade balance in these manufactured products has remained steady at about $9 to $10 billion a year since the mid-1960's. The fact that the fractional surplus has decreased in the last decade is a cause of increasing concern to many people. To other observers, the faster growth rate of technological capability in some other countries and increased imports of their products to the United States are natural results of the general recovery from World War II and the fact that a lower base enables higher rates of increase. Factors other than technological advance are also important.

The range of technical spin-off into advanced industries from Government-supported missions, such as defense, may be consid-

[2] Daniel Bell, Chapter 5: *The Measurement of Knowledge and Technology*, "Indicators of Social Change," Russell Sage Foundation, 1968.

erably narrowed as new objectives emerge. For example, Government involvement in new undertakings in health care delivery will not provide as broad a field of new industrial departures. In general, it is unlikely that Government initiatives in the service industries will provide as much spin-off as they have in the goods industries.

There is a real danger that, without Federal incentives for research and development, we shall witness a spreading of technological enervation and obsolescence in industry. Special attention should be given by the Federal Government to those areas of applied research which give promise of leading to new industries but which are of such high risk or require such long term investment that single industrial groups are unable to pick up the challenge. It is not clear, to be sure, that incentives for research and development will save some industries.

The scale of the investment required for needed research is often so large that many United States industrial companies are at a severe disadvantage in competition with government-industry combines abroad.

As to the immediate future, the relationship of international trade and the success of our technology is of profound importance. There is danger of a deterioration of trade balances in technologically intensive products, such as computers, aircraft and electronics, and also in general manufactures, such as minerals and feeds. If we are to compete successfully in the future, we must maintain a continuing tradition of technological innovation supported by a strong scientific base and engineering competence.

This country would benefit from small scale efforts — seemingly mere beginnings — as well as large ones to stimulate industrial innovation. Therefore, appropriate agencies like the Small Business Administration should continue to encourage and support ventures where technological innovation is vital. It has been found that individuals and small technologically based industries are responsible for making far more than their proportionate share of important new technological innovations. Examples of this are rockets, Xerography, the gyrocompass, the jet engine, and the Polaroid camera (see Appendix C).

We should like to point out, however, that governmental incentives intended to stimulate small technical enterprises or individual inventors are likely to cost little but may yield large benefits.

That small industries merit attention does not mean, however, that the large industries can be neglected, because they provide by far the greatest volume of the research and development which is indispensable to technological and economic progress. They also make a fair share of the important innovations. Inventions which have come out of the laboratories of large corporations include nylon, the transistor, Freon refrigerants, television, polyethylene, neoprene, Plexiglass, fluorescent lighting, and the diesel-electric locomotive.

Both large and small industries are necessary to a strong economy, although their requirements and contributions may be quite different. Among the small industries of today are some which will be the large ones of tomorrow.

NEW FEDERAL ROLE WITH RESPECT TO TECHNOLOGY

We believe that the foregoing discussion points up a newly emerging and enlarging role and responsibility for the Federal Government: that of maintaining and developing the technological base of United States society, and that of assuring the rapid translation of new knowledge into the products and services needed by the Nation and its people.

Therefore, we recommend:

RECOMMENDATION I. GOVERNMENT AID IN SUPPORT OF INDUSTRIAL TECHNOLOGY

Government policy should encourage the injection of basic and applied research activity into mature industries, and the maintenance of a high level of such activity in technologically advanced industries.

The Federal Government should encourage essential research activity through direct and indirect financial incentives on a trial basis through both traditional and new modes of cooperation among industrial, governmental, nonprofit, and academic institutions. Such activities might include, but not be limited to:

Providing financial incentives for joint applied research activities between academic institutions and industrial associations.

Providing matching funds for special cooperative efforts for applied research organized within or alongside universities, non-

profit, and governmental installations for those industries so fragmented as to be unable to act effectively alone or in concert.

Exploratory grants and contracts are desirable immediately as much trial and error is required before large scale funding of research can be most effective. Some NSF programs in applied research might be used for this purpose. With careful management, valuable models could be provided for larger scale operation. Existing national laboratories should be utilized to the extent practicable, consistent with their areas of competence.

The Federal Government should assume responsibility to insure adequate and continuing development of new technologies to upgrade mature industries, maintain the present edge in technology advanced industries, and generate new industries.

As one way of discharging this responsibility, the missions (used in this Report in an informal rather than strict statutory sense) of appropriate agencies might be expanded to provide greater research and development capability, including support, when public interest warrants, of industry research and development.

The Department of Commerce already has responsibility for such technical agencies as the National Bureau of Standards and the National Oceanographic and Atmospheric Administration. Close liaison should be maintained between the Department of Commerce and the research components of other mission-oriented agencies including the Departments of Transportation and Housing and Urban Development.

With experience, a need may become evident for an additional center or locus of concern — such as a National Foundation for Technology — to identify areas requiring innovation and stimulation and to catalyze new initiatives (e.g., industry-wide centers of research and development, associated in some instances with universities).

Decisions as to which industries need assistance, and how much, should be made, after careful study, by those Federal agencies most concerned. The Government role should focus on but not be limited to applied research. As to development, while there may be a special burden of proof as to the Government's taking this role, there will be cases where a justification exists.

There will doubtless develop gray areas in which the Government mission is vague or controversial. Choices will be difficult, and hard decisions must be made among the possible options. The proper role of Government with respect to technology has never been more difficult to define and implement than it is today, and this task will become even more difficult as the future unfolds.

Beyond this, policy decisions will need to be made as to how far the Government should go in most areas, as, for example, in the encouragement of research and development and new technology in certain industries for the sake of the general economy. Consider industries which for one reason or another are content to import their technology or are unwilling to engage in the necessary research and development to advance their own technology. Is it not in the long range public interest that no major industry should be allowed to stagnate for this reason? It is possible that the Federal Government may be justified in undertaking initiatives in such situations, even though no Federal mission is directly involved.

Government involvement must, however, become a stimulus and a catalyst for developing continuing growth without becoming a crutch. If mechanisms can be devised whereby the Government can stimulate or initiate new research and development, especially in fields which are broadly applicable to a number of industries, stagnation can be avoided, overall productivity can be increased, and industry should be able to continually reinvest.

SCIENTIFIC AND ENGINEERING MANPOWER

The research-technology-productivity sequence will be successful only if highly trained scientific and engineering manpower is available to staff it. The educational system required to produce this manpower must be able to furnish instruction in a wide spectrum of the basic sciences and advanced engineering skills as well as to provide experience in research. Engineers and scientists must also be motivated during the educational process to take serious interest in potential contributions of their subjects to societal needs.

As national objectives shift toward societally oriented goals, engineers are heavily affected by the resulting dislocations. For

example, current technological unemployment is obviously related to changes in national priorities for defense and space. The present crisis entails dislocation and reemployment for many. One hopes that the situation is only temporary and can be resolved by a combination of measures such as retraining, centralized exchange of information on employment opportunities, and flexible adjustment among fields of science and engineering. Many of the professional societies, among them the American Institute of Physics, the National Society of Professional Engineers, and the Institute of Electrical and Electronics Engineers, are taking active steps in these directions. There is a responsibility on the part of Government to do its utmost, on occasions of major shifts in priorities, to make provision to cushion the impact upon persons affected by consequent changes in employment patterns.

The science and engineering manpower situation has changed rapidly from one of chronic shortage to apparent surplus, at least in certain fields. The immediate job market is confusing, influenced as it is by changing factors such as Federal budgetary cuts, transitory business recessions, and inflow of technical manpower from abroad. Long range manpower forecasts are somewhat more reliable because they depend on population trends and estimates of economic growth. Some authorities (Reports of the Engineers Joint Council, also article by Wallace Brode in *Science*, July 16, 1971) suggest that shortage rather than surplus of technical manpower may characterize this century from the late 1970's or early 1980's on. This is most likely to occur if the Nation continues strong in technology, and particularly if it really works at finding solutions to its societal problems.

None of the projections has attempted to take account of the employment requirements for attaining an improved social structure, enhanced quality of life, or strengthened technology. Considerable redistribution of scientists among fields may be expected to occur, and if fewer may be employed in graduate education, more may be needed in other roles. If this Nation were not to produce enough scientists and engineers to carry forward our "knowledge society," our national life would suffer with respect to standard of living, competitiveness in world markets, national security, and, most serious of all, manpower resources for coping with our sociotechnological problems.

TECHNOLOGY FOR PUBLIC GOODS AND SERVICES

We have discussed what we see as a newly emerging role for the Federal Government for continuing analysis and strengthening of technology in the private sector of the economy. We believe there is emerging also a comparable role for the Government with regard to that technology which applies primarily to the public sector.

The national economy is rather rapidly approaching what is sometimes described as a "postindustrial" phase. Thus, there is occurring an economic transition in the sense of moving from a manufacturing-intensive to a service-intensive national economy. At present, for example, approximately two-thirds of the employed labor force are in the service sector (including education, health care, recreation, the professions, and clerical functions). The service sector also includes goods "purchased" collectively (e.g., clean air and water, fire protection, civic order). Housing and urban mass transportation are other examples of services that benefit individuals but are believed to have sufficient "external benefits" for society to be publicly subsidized. But "productivity" in almost all these areas has lagged behind productivity in the manufacture of capital and consumer goods for the private market. The need for injection of existing and advanced technology in the production of public goods and services is substantial, but obtaining the transfusion is made supremely difficult by a common characteristic — a market large in the aggregate but composed of a multitude of small, scattered pieces. Thus, Federal policy should be increasingly directed to improving the productivity in these fields and establishing objective criteria of performance.

The opportunities for applying existing technologies and developing new ones in the public goods and services sector are enormous, examples being housing, transportation, and health care. Further discussion of those fields occurs in Part II and includes consideration of their interrelationships as themselves constituting an area in which technological approaches can be helpful. Another kind of example is presented by the need for research and development on the causes and prevention of fires, and fighting fires.

There are other areas where public needs could be met by technology which already exists or would not be difficult to acquire, but where at present the profitability to private firms is ques-

tionable. In other words, there is no present commercial market to pay for the development of the technology, but the stakes for society may nonetheless be of great importance. An example is earthquake engineering. Under a National Science Foundation program, data are being acquired which should lead to design of economically feasible shock-resistant structures in earthquake zones. This program also involves the development of means of assessing seismic risks, and study of the social and economic aspects of earthquakes.

This discussion, in our opinion, points to a need for considerably greater governmental support in those areas where research and development may otherwise be expected to lag for want of cohesive concern or hospitable environment.

Therefore, we recommend:

RECOMMENDATION II. TECHNOLOGICAL SUPPORT FOR PUBLIC GOODS AND SERVICES

Key technologies essential to the attainment of societal goals, but not presently commercially viable, should be continually developed, strengthened, and renewed through Government-aided research and development.

Some of these problems would be more appropriately dealt with by state or municipal government elements, but the Federal Government should provide leadership through initiatives, incentives, and setting of standards.

This responsibility for the stimulation of technology primarily associated with social needs may be met in part by expanding the missions of existing Federal agencies and particularly by substantially strengthening their research and development capabilities. With few exceptions, these agencies now concentrate on relatively short term, quick-payoff projects. A much stronger commitment is needed to enable them to build longer range research and development capabilities in their areas of responsibility, to which universities as well as industry may contribute. The full spectrum of research and development is required, looking toward exploration of alternative possibilities. The commitment should be on a scale to solve the problems.

PART II

POLICY FOR TECHNOLOGY IN SUPPORT OF SOCIETY

Part I advocated the enlistment of public support for development of new technologies for private and public goods and services. This chapter discusses the means of enlisting technological support in approaching broad societal problems.

There is now occurring a clear-cut transition in our society's approach to technology: in its development by engineering and science, in its deployment by the private sector, and in its support and utilization by the public sector. This transition is exemplified by a movement from the long-time predominance of our concern with industrial technology and the technologies of war and cold war toward a concern for a heightened and broadened use of technology in solving the problems and meeting the needs and desires of society. Profound adjustments are under way, in response to radically new patterns in society's desires as to what its technology should do and to the sometimes abrupt decisions as to what technology should not do. This is a period in which a new relationship must be developed between the American society and the technology which pervades so much of its existence. The ultimate nature of this relationship is a major issue to which a public policy for technology must be addressed.

The development of new social attitudes toward technology presents new challenges and opportunities for technology. Environmental and aesthetic requirements have been given new stature comparable to that of the traditional economic constraints. Developments which were undertaken in good faith under one set of considerations are being judged by new criteria, and years of conscientious and honest effort are suddenly condemned and suppressed on grounds which few could have anticipated when the initial development was undertaken. But once this time lag of technology behind society (the opposite of the conventional wisdom) is understood, it seems clear that the new criteria increase rather than decrease the technological options available. Hosts of technological opportunities which were excluded years ago for reasons of uneconomic competitiveness or the preferences

of society suddenly become open for reevaluation (e.g., electric automobiles, coal gasification, high-speed trains). Thus, from the standpoint of the engineer, previously restrained by narrow economic criteria, new ground rules which everybody must meet greatly broaden his opportunity and enhance the importance of his role. Suddenly, many different types of automotive power plants have to be reassessed. New methods of generating and transmitting electrical energy have to be studied. Hundreds of empirically honed industrial processes are suddenly up for reexamination from a more searching and analytical viewpoint. Thus, the commitment to problem solving, which is inherent in engineering, has the beneficial consequence of transmuting requirements into incentives and, thus, challenges into opportunities. There can be justifiable confidence that from just that process of transmutation there will be derived effective new technological performance in meeting the needs and desires of society. The forecast is optimistic, not pessimistic.

But it is realistic, not pessimistic, to acknowledge that the new pressures are powerful and as moving forces have developed great momentum. It is realistic, not pessimistic, to recognize that, in the absence of a public policy for technology within which the constructive potentials of these forces are accepted and given their legitimate functions, the consequences to technology could be damaging. It is as important to society as to technology, for example, that their evolving relationship leave room for the play of those faculties of innovation, intuition, creativity, and on occasion sheer genius, which always have so much to say about where the leading edge of technology is located.

Many of the problems facing us today are the result of the increasing size, complexity, and affluence of our society. Over the last 30 years, during which time our population has increased by 50 percent, the population of automobiles has increased by 350 percent. In 1940 the automobile was considered to be no more a source of pollution than the horse-drawn wagon which it displaced. Over the last 50 years, during which time our population has doubled, our requirements for energy have quadrupled. Today our scale of use is so large that the by-products of energy utilization are noticeable and significant. U.S. per capita energy consumption now is about a million BTU per day, enough to boil 125 gallons of water for every American each day. For every

calorie we consume as food, 80 calories must be expended to provide the goods and services we require. But, on the other hand, to achieve our standard of living in a technologically primitive society would take well over 80 servants for each man, woman, and child.

There is one car for every two Americans today, not in spite of society's desires, but because we continue to buy them and to depend on them. Nor is our vast energy consumption counter to society's desires for air conditioning, washing machines, and the like. If we have failed at all in our utilization of technology, it is because we have overlooked or neglected to look at long range consequences prior to widespread development and use.

As the size of our society has grown, so too has the complexity. We now appreciate that energy, resources, population, and environmental quality are all interrelated elements which cannot be dealt with individually and independently. Similarly, transportation, housing, health care, education, and communications are all elements of the broader urban and regional system, to be dealt with in the totality of the living environment. A program aimed at one element can have subtle repercussions in other sectors; programs aimed at symptoms rather than causes may be ineffective or even detrimental.

The large systems to which we refer present major and seemingly intractable problems. The effort required to examine them in their totality is so vast and the time required so long as to discourage the attempt, at least up to recently. In the near term, we shall continue to formulate programs aimed at solving portions of these problems. But the question is whether we can continue to do so without exploring on a large scale the long term consequences and opportunities of our near term actions.

EXPLORATION OF SOCIETAL ALTERNATIVES

Above the clamor of the ongoing debate to define the "quality of life" and to develop programmatic specifics to improve it, there can be ready agreement on a number of broad societal purposes of a long range nature. For example, we would all like to see:

A living environment conducive to the development of present and future generations. For at least the remainder of this

century, this environment for an overwhelming majority of Americans will be urban-suburban complexes which are interrelated in regional patterns.

Job opportunities in concert with the capabilities of the population. To reach and sustain full employment, we will require 35 to 45 million new jobs over the next three decades. These must offer not only attractive careers in performing skilled functions to an increasing number of college-educated young; but attractive opportunities in unskilled and semi-skilled employment for those who do not attain high levels of education or training.

Continued enhancement of the standard of living. In addition to making more broadly available in the population the goods and services now largely within reach of only upper incomes, it is essential to provide better education, health care, and housing for those at the lower end of the economic spectrum. Continued enhancement of productivity, especially in the service sector, is required to meet this need.

Balanced international exchange of knowledge, goods, and services. As we continue to help developing nations, we must also compete effectively with the increasing number of developed nations while seeking to move toward the elimination of restrictions in the international exchange of knowledge, goods, and services.

Enhancement of environmental quality and preservation of natural resources. In addition to continuing the effort to achieve and maintain a cleaner physical environment, we must face the fact of limits on the earth's resources, and recognize that exhaustion of a resource narrows the choice of options of future generations.

The means of attaining each of these goals includes a high technological component and each, therefore, presents challenge to the engineer and scientist. The order of priority which society chooses for undertakings of such magnitude will deeply influence the future directions of technology in all its aspects.

It is not supposed that such goals can be reached quickly, or even that major efforts can be made simultaneously with respect to all of them. The resources required to eradicate slums or repair our environment overnight simply are not available. We do not

have adequate mechanisms to reeducate or retrain rapidly people displaced by foreign competition or changing priorities. To develop fully the techniques, facilities, and personnel to upgrade health care services will require many years of extensive effort. Thus, in the near term, trade-offs must be made. At present, Government is so beset by immediate problems and crises that too little time and energy remain to devote to longer term opportunities.

On the other hand, we do have sufficient flexibility in the long term to bring the objectives stated above into concert with one another. We should seek the rationale for turning short term conflicts into long term opportunities. For example, let us strive to develop job opportunities in goods and services which will aid in renewing our cities *and* increasing our exports. Let us strive to develop educational patterns which will permit displaced workers to *upgrade* skills to more productive job functions.

The problem of urban and regional development, as an example, illustrates two concepts which have special importance in following the labyrinthine path toward the goals just stated. One is the recognition of the interdependencies and interrelationships among different categories of activity in society which have tended in the past to be viewed as separate problems, their internal dynamics insulated in each case from the others, but are now perceived more and more clearly as parts of larger entities, the "systems" referred to before. The other stresses the need for avoiding to the extent possible, in dealing with immediate problems, measures which later might interfere with progress toward broad and sustained fulfillment of our society's aspirations. First aid is often an inescapable requirement, but its consequences must not be detrimental to the restoration of full well-being.

The continuous process of reviving and renewing our cities and their environs is a problem which illustrates the need for exploring the long term as a guide to near term action. It is also a field of opportunity in which technologists can make significant and varied contributions.

An urban area or region can be viewed as a complex pattern involving the interchange of goods and services which are needed

or desired by its inhabitants. These goods and services include, but are not limited to, the following:

- Housing
- Transportation
- Employment opportunities
- Education
- Health care
- Public safety
- Power
- Environment
- Communications

In the past most sectors of society — academia, industry, and government — have been compartmentalized along the lines of these categories in order to organize and direct efforts to deal with them. In the process we have traditionally reacted sequentially to those sectors which appear to present the most pressing problems. But as our cities and regions have become more complex, we have begun to appreciate the interdependencies of the various components. Traffic congestion is not due simply to inadequate roads, but is partly the result of high population density and large distances between homes, stores, and jobs. Crowding cannot be relieved simply by high-rise housing without taking into account the socio-economic processes which generate incentives for rural-to-urban migration. Urban poverty does not present simply a humanitarian obligation to be met by welfare and higher taxes, because the mismatch between people and jobs will be worsened by rising taxes and the resulting outward migration of industry and the wealthy and inward migration of the poor.

Thus, it is clear that the components of urban life are interrelated in a highly complex *system*. If one part is modified, other parts are affected. Decisions must be made in terms of the total effect rather than of partial ones and made with some understanding of long term consequences.

By the same token, the suburban-urban complex is part of a larger regional system whose components must be viewed in proper perspective. For example, transportation systems can no longer be viewed as a dependent variable to be based on only *10 to 20 year* projections for housing, industrial sites, educational and health care facilities, and so on, because, once built, a transportation system can have a powerful effect on placement of

housing and other structures for the next *50 to 100 years.* The magnitude of the investment required for a transportation system greatly reduces the flexibility for future options in other subsystems. Thus, transportation options for the distribution of goods, services, and people must be based on *long term* analysis of potential placement of homes, jobs, schools, hospitals, etc. Alternatives to direct transport of people — such as two-way cable TV for shopping or for conferences — need to be explored as options to new roads. The environmental impact of roads, highways, and motor vehicle power plants must be considered. Furthermore, alternative transportation systems which may not appear feasible by today's standards require research on a continuing basis so as to enhance future flexibility.

Similarly, an analysis of new methods of providing health care — the costs, benefits, availability, and utilization — must account properly for the interfaces with other components such as communications, education, and environmental quality. Advanced communication systems offer numerous opportunities for remote diagnosis and information retrieval; new educational programs are necessary to foster public acceptance.

There are numerous other examples which attest to the need for a concerted view of our complex social system. The engineer trained in systems analysis can make significant contributions to the understanding of long term consequences and future opportunities within such a system. In the 1950's and 1960's engineering methods such as systems analysis and technological forecasting were developed with a view to refining decision making to improve the effectiveness of research and development in the defense and aerospace fields. Although those developments represented a major innovation, their proponents perhaps sought to extend their use too rapidly into fields beyond those purely technological, involving nonscientific value judgments. But as more and more social and behavioral scientists participate in their development, these methods will undoubtedly reach high usefulness in the analysis of social systems and the development of strategies for coping with societal problems.

Over the last few years, there has emerged a serious attempt to apply the systems approach to complex social problems. It is termed systems dynamics and is an outgrowth of the established and successful approach to analysis of industrial dynamics. The

technique involves development of models which represent the motivation and behavior of groups of people and institutions. For example, migration to an urban area is related to the perceived "attractiveness" of that area relative to other locations. Components of attractiveness involve job opportunities, housing availability, and kindred factors. An effort is made to quantify these elements. The dynamic behavior of the model is simulated on a computer.

The systems dynamics approach is in an embryonic stage. Models developed to date are regarded as naive and incomplete. But it represents the beginnings of a framework — a way of organizing information in an analysis so that we can properly account for multivariable interactions and interdependencies. An intensive effort is needed to refine models and quantify parameters such as social values.

There have been many criticisms of the systems approach to societal problems, notably from social and behavioral scientists themselves. The translation of usually nonquantified values (such as aesthetic, behavioral, or cultural choices) into numerical units for ease of application to computer usage generally has not been very successful. The "pseudo" cost-benefit analysis derived from this process has been invalid more often than not. However, we must navigate these areas of ignorance if we are to convert our thinking on societal matters to more effective forms. The entire value-methodology process is an area in which large scale research and development appears to be warranted, and the social and behavioral scientists should be encouraged to participate with engineers in this pursuit.

The lack of adequate knowledge and methodology should not be viewed as an insurmountable barrier to developing models in the systems context. Jay W. Forrester, a proponent of systems dynamics applied to social systems, presented a forceful argument for the use of models in testimony before the Ad Hoc Subcommittee on Urban Growth, House Committee on Banking and Currency. His point is that we all use models constantly for decision making. Any mental image of the world around us is, in a way, a model in which selected concepts and relationships are used to represent the real system. "All executive actions are taken on the basis of

models. The question is not to use or ignore models. The question is only a choice among alternative models." [5]

Complex systems have many special and unexpected responses which cause many of the failures and frustrations that are experienced in trying to improve their behavior. What may intuitively seem appropriate to a situation may actually be the wrong approach; cause and effect may not be closely related. The cause of a difficulty may lie far back in time from the symptoms or in a completely different part of the system. One may find a plausible cause near in time and space to the difficulty, but sometimes the apparent cause is only a coincident symptom moving in time with the problem. There is the possibility that a symptom is treated and not a cause, with an outcome which lies between ineffective and detrimental. The conflict between short term and long term consideration is another contributing factor. Very often the actions that seem easiest and most promising in the immediate future can produce even greater problems at a later time.

These considerations — to overcome "counterintuitive" obstacles, to avoid the pitfalls of the "quick fix," and to avail ourselves of the benefits of long term opportunities — lead toward Recommendation III which calls for a major effort to *explore* future alternatives to define the options, opportunities, dangers, and costs. Required is an integrated and orchestrated examination of the problems and opportunities within every component of the complex societal system. The exploration must be comprehensive; it must be multidisciplinary in the academic sense — involving technological, economic, sociological, and political viewpoints — and in the broader sense of involving public and private institutions and representatives of major groups of society.

Exploration is vital to define an expanded range of alternative opportunities and make them as specific as possible. The search for objectives implies a new approach that would systematically attempt to relate problems emerging from new societal demands to actual and predictable techno-economic possibilities. It is no easy task — indeed, many doubt that even the best minds are up to it — but there appears to be no other way. Hence, the effort must be made, and immediately begun, to develop the techniques and capabilities that will be necessary.

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[5] *Hearings*, October 7, 1970.

Specifically, this recommendation is offered:

RECOMMENDATION III. EXPLORATION OF FUTURE ALTERNATIVES

There should be established, on a continuing basis, substantial groups of full-time professionals of outstanding competence to develop the capability (methodology and manpower) to explore specific large problems of national importance, and to explore alternatives for dealing with those problems. The groups would develop alternative exploratory approaches, lay out several possible trials, and devise appropriate experiments. So equipped the decision-making institutions of our country may better guide its future.

Initially, the energies of these groups would be concentrated on achieving as a first product the required development of capabilities, methodologies, and manpower. In the long term, with the aid of this process, our Nation would be better equipped to establish priorities and implement national goals.

The immediate formation of three exploratory groups is suggested, each to concentrate on one of the following clusters of major problems:

A. *Urban and Regional Design.* It would be the responsibility of this group to develop a flexible methodology for understanding the dynamics and interactions of urban and regional systems, the results of which could be applied to specific localities; to identify and develop means of quantifying parameters describing social values and societal aspirations; and to develop strategies for local economic, legal, and political arrangements, which can provide incentives for long term enhancement of the living environment. The explorations of methods and of courses of action would seek to embrace all major elements or subsystems such as housing, transportation, health care, education, communications, and the like.

B. *Resources, Environment, and Population.* The responsibility of this group would be to develop methods for understanding and beneficially influencing the impact of man upon the environment and of the environment upon man; to develop an expanded knowledge base of the subsystems of air, land,

water, energy, and life that surround man; to establish, for varying levels of population, the relationships of resource limitations and pollution generated by man's activities to the quality of human life, and to evaluate how technological advances may modify those relationships.

C. *The Techno-economic System.* The explorations of method and action by this group would seek to define the relationship between research and development on the one hand and innovation on the other and, in turn, between innovation and productivity; to assess the distribution of employment activities necessary to support progressively more satisfying standards of living; and to explore the educational patterns needed to match work with intellectual capabilities and psychological needs.

The size of these bodies would be commensurate with the size and complexity of the problems. It is anticipated that the scope of the problems, as described above, may be redefined in the process of formation of the exploratory groups or at a later time. We realize that there are significant interrelationships among the components of these three tasks; they are all elements of our "national system." The suggested clusters represent an attempt to define major subsystems for which broad, mission-oriented objectives can be defined. It is recognized that a group might, when desirable, "subcontract out" subsets of the work to any institutions of the required capability. In some cases, there might be recourse to an existing Federal agency possessing the in-house capability to deal with a problem of major dimensions.

In the exploratory stage, the need for dedication to the public interest cannot be overemphasized. Objectivity with a minimum of interest-group bias is essential to insure responsiveness to the best interest of the public. Thus, exploration should be protected from direct "pressures" from any sector of society, including those resulting from the periodicity of the political process. On the other hand, feedback from the Legislative and Executive Branches is essential.

It is essential that the exploratory groups work closely with existing and any new institutions or agencies which are concerned with important elements of these massive problems.

It is specifically intended that existing agencies should be enabled to strengthen themselves to the point of possessing in-house

capability to perform research and development in behalf of the exploratory groups, or obtain it outside by contract.

Although the comparison is less than exact, such agency functions would resemble that of the Advanced Research Projects Agency (ARPA) in the Department of Defense.

The results of techno-economic exploration would be expected to contribute to an understanding of the innovation process and, thereby, aid existing and new institutions concerned with setting priorities for Federal support of applied research for technology.

Coupling the exploratory effort to the public sector is also essential. Provision should be made for periodic reports to the Nation to stimulate widespread and intensive debate.

It cannot be predicted in advance when such exploration will yield insights pointing the way toward new applied research directed at concrete solutions or which may indicate reformulation or reorganization of initial objectives. It will be necessary to wait, recognizing that this is the inherent nature of the exploratory process. There will often be temptations to proceed on the basis of incomplete data and partial insights. These temptations sometimes must be followed and other times rejected.

Although the exploratory groups would be expected to propose methods of implementing each alternative, their responsibility would not extend to selecting the options for implementation.

Their main function would be to develop methodology and manpower, and to put forward a menu of alternative solutions from among which choices can be made by the established decision-making processes of Government. Choosing options for implementation must remain the responsibility of the citizenry as a whole, acting through their elected officials. In no way should the exploratory groups impinge on the sovereignty of the political process as the means of establishing priorities.

The strength of the free enterprise system shows up most forcefully in the implementation phase. In many respects, institutions already existing in this country may be well equipped to handle implementation when exploration has been completed and choice of alternatives decided. Once the requirements for implementation are established, the conventional market forces and the free enter-

prise system may be expected to operate effectively, as they have in the past.

THE INTERFACE OF TECHNOLOGY AND SOCIETY

Just as the scientist and engineer must take greater cognizance of the emerging social requirements of technology, there also should be greater emphasis placed on public understanding of technology. As the ultimate decision maker in our society, it is necessary for the public to appreciate what technology can do and what it cannot do; what it must do and what it must not do.

A critical factor in trying to anticipate potential dangers of a new technology is knowledge of how the technology will be deployed and what safeguards will be instituted to control its use. In many cases, there are legal and economic arrangements — at the discretion of society — which govern the availability and control of technologies. These have been referred to as the *supporting systems*.[6]

Whereas the automobile and road building are technological developments, the supporting systems include rules of accident law, automobile insurance schemes, traffic police, and policies to determine where roads should be built.

Long range analysis might have led on past occasions of important decision to choice or encouragement of different technologies (e.g., bioenvironmental pest control rather than chemical insecticides); however, the engineer alone has not had the background to predict the types of supporting systems society would devise to govern the use of technology. In a large number of cases, if not most cases, a higher sophistication in societal decision-making processes might point to different supporting systems rather than different technologies. These might include, for example, different revenue sources for the television industry, different cost-accounting procedures for pollution, or different formulations of building and zoning regulations.

Along with the lack of analysis and forecasting, a factor which has contributed significantly to the abuse of technologies is the

[6] *Technology: Processes of Assessment and Choice*, National Academy of Sciences, July 1969.

scale of use adopted by society. Prime examples are per capita consumption of energy, pesticides, and automobiles. Sixty years ago it would have been simple to predict that the internal combustion engine would chemically pollute the atmosphere more than steam or electric engines, but few would have predicted that in 1970 there would be one car for every two people. Since the number of horse-drawn carriages was small in relation to the population, it is unlikely that more than a few prophets would have foreseen the scale of use of the "horseless carriage." Similarly, over the years there have been periodic predictions of per capita energy consumption and, in almost every case, it was hypothesized that consumption would level out after ten years. After all, how much more energy could we consume? And yet, consumption continues to rise at a steady rate.

In the future an endeavor must be made to assess more accurately the potential scale of use. In striving to enhance the standard of living of the entire population, it might be anticipated that everyone will want and be able to afford "a good thing." If there are upper limits to the scale of use beyond which a good thing is harmful, we must devise equitable means for limiting its use, or find alternatives to satisfy the function or need. Although our society has been reluctant to "ration" supply, in many cases it may be the only alternative to the development of a national consensus for limiting population.

The previous subsection discussed the need to develop a process for exploration of future alternatives. A beginning must be made now in providing the public with sufficient background to make rational choices among such alternatives. It is not suggested that people at large should be taught how to do engineering. There is need, however, that they be given a grasp of some basic concepts and the process by which association of various observations produces an idea. For example, to generate electricity, a fuel must be consumed and, thereby, *a resource depleted;* waste-heat generation and the need for its disposal at a power station using a heat cycle is a fact of life *imposed on us by nature;* all of the electricity we consume is eventually converted to heat by *irreversible processes.* The mean temperature of the earth is set by a *heat balance,* an element of which is the amount of energy consumed by man. Local and global climate is related to man's activities through the heat balance and man-made contributions to the composition of the atmosphere, although the exact nature of these perturbations to

climate has yet to be fully understood. These are but a few of some basic concepts which are important facts of life in today's technological society. In a democratic society, the public must have a voice in decisions concerning population control, power plant siting, air pollution control, and weather modification; therefore, they must be given a basic understanding of some technological concepts.

The public must also appreciate the capabilities and limitations of the technological process. Engineering is far less an exact science than is physics or mathematics. Empiricisms, extrapolations, and assumptions, which are required when data and theories are lacking, necessarily introduce uncertainties in proposed solutions. In many cases, there are alternative solutions lacking quantified criteria as guides for chosing the best one. Thus, many decisions are based on subjective judgments of individuals, and an informed public will not expect open and shut decisions in all cases.

It has usually been assumed — by scientists and engineers as well as the lay public — that technological subject matter is too complex for those not majoring in it. In an attempt to disprove that notion, the Engineering Concepts Curriculum Project was undertaken in 1965, under the sponsorship of the National Science Foundation, to devise a high school level course on systems and computer technology. A text has been published,[7] and the course is now taught in many high schools. Although the level of the subject material may still be too sophisticated for the entire high school population, this first effort has demonstrated that some concepts of technology can and should be made available to a broader cross section of the populace.

Much of the effort in public enlightenment must be addressed to persons outside the formal processes of education, for the simple reason that there are generations of Americans in that group who are enfranchised to participate in, and criticize, complex policy making and decision making involving technological alternatives. We look with favor on suggestions that industry should generate programs to enlarge public understanding of the technology it places in the public hands. Such an undertaking would be far more than quixotic. It can be supposed that a society like ours

[7] *The Man-Made World*, McGraw Hill Publishing Co., 1971.

which has been fascinated by technology from earliest days would provide a receptive audience.

For the generation now within the formal processes of education, and its successors, the means of fostering such understanding are available, but need to be developed so that ultimately it will be general within the society.

For the foregoing reasons, we recommend:

RECOMMENDATION IV. PUBLIC UNDERSTANDING OF TECHNOLOGY

The National Science Foundation and the Office of Education should as a matter of long range concern seek to promote the teaching of the principles and nature of technology at all levels of formal and informal education. The existing NSF program on Public Understanding of Science should undertake, within its existing field of responsibility, efforts to enhance public understanding of technology and how it differs from science. The Federal Government and industry should mount parallel efforts to convey that understanding through channels outside the classroom.

TOWARD BALANCED TECHNOLOGICAL GROWTH

Although Recommendations III and IV are offered for immediate action, arriving at major findings or results will take time. The exploratory groups will probably take several years to establish methodology and develop the requisite manpower; they will be doing well to produce any major recommendations within the first five years after their inception. Public understanding of technology and its bearing on major policy issues facing society will undoubtedly take longer, Recommendations III and IV are designed for longer term impact. But decisions cannot be postponed on the multitude of matters requiring near term action until all the facts are in hand and the public has had a chance to digest them and express its informed voice.

Of these near term technology-based concerns, one of the most pressing issues for Government is how to achieve a balance between opposing forces: between unhampered evolution of new technologies and constricting controls; between innovation and restraint; between rapid growth and no growth. The task is one

of finding a path between two extremes: the position of a highly vocal segment of society which wishes to impose the strictest kind of restraints upon technology, and the position of an opposite group which fears that restraints can mean only the stifling of innovation, leading to technological stagnation and the most deleterious effect upon our economic performance, domestically and internationally, and upon the quality of life of the American society.

Part I dealt with the need for Government initiatives to stimulate innovation through direct and indirect support of research and development. The imperatives for Federal responsibility — to update aging technologies and to bring forth new ones — are imposing. A continuous stream of new developments is essential if we are to compete effectively with growing technological capabilities abroad; new technologies are a prime source of the new industries we look to for expanding employment; increased efficiency in producing conventional goods and services is necessary to free scarce resources for eliminating poverty and cleaning up the environment, while enhancing our standard of living. In addition, there are the intangible benefits of researching and developing technologies which do not appear economically viable today, but which are necessary to have at hand to preserve the options for future generations; hence, the recommendations in Part I.

On the other side of the ledger, there is perceptible among public attitudes toward technology a potential tendency to throw a strong bridle upon it and hold it on a tight rein. "There is now even a severe case of antipathy toward technology that was expressed in the recent past only by a few romantics," said the 1970 report of the President's National Goals Research Staff, "Toward Balanced Growth." Whether justified or not, there are many who attribute some of our major contemporary problems to ill-considered exploitation of technology: the tensions and frustrations of congested cities; the dangers of a polluted and despoiled environment; the potential of thermonuclear destruction, the hazards of surveillance and manipulation of private thought.

Adjusting to these new pressures presents unfamiliar difficulties to the engineer, who historically has been primarily concerned with the so-called "economic constraint" and had learned to live with it. The new environment is more difficult to deal with, partly because there have been introduced into it new social attitudes

which are not easy to define, analyze, and measure, and partly because these have shown themselves so suddenly as to constitute a surprise, a changing of rules in the middle of the game. They have been given focus and force by legislative enactments, executive actions, and judicial determinations, which up to now have occurred for the most part in not far from random fashion.

The existence of that school which would strictly restrain technology is only the extreme reflection of a reality. Short of the extreme, there is a substantial segment of the American society which, while acknowledging the vital role of technology in the economy and while eager to enjoy its contributions to the quality of life, is disquieted by some aspects of technology's impact on society and seeking some means of controlling it while preserving its full usefulness. This disquiet is what underlies the movement for mechanisms of technology assessment, by which the attempt would be made to screen out such newly emerging technologies as seem to have a potential for adverse social effects if broadly introduced without adequate safeguards.

Recommendation V includes a purpose of allaying that disquiet, which in a range of intensities from vague to acute can indeed have an inhibiting effect upon technological progress, by answering questions and removing (or, on occasion, confirming) causes of concern in the society. It would enhance the public interest by providing a point of recourse — a "credible group" — for independent determination of the probable consequences of technological departures. By experience and learning, it is hoped, such bodies would evolve into an institutionalized function of technical analysis and assessment.

The recommendation:

RECOMMENDATION V. TECHNOLOGY ASSESSMENT

There should be formed in appropriate agencies, including the National Science Foundation, or as separate bodies if need so dictates, groups responsible for the long range analysis and assessment of technological systems of broad public importance. It is urgent that new capabilities be created to evaluate the societal benefits of new technological developments in advance of their wide scale dissemination and call attention to their potential hazards, undesirable by-products or side effects. Such groups should make generally available

to the public information regarding comparative costs and values as a basis for decision-making in order that appropriate safeguards may be established. They could call upon all national advisory and research resources to provide the many diverse substantive skills required in assessment.

It is recognized that some existing agencies and institutions undertake analysis and assessment as a major part of their mission. These include, but are not limited to, the Environmental Protection Agency, the Food and Drug Administration, and the Federal Communications Commission. The Environmental Impact Statements required by the Environmental Policy Act of 1969 provide an example. The Council on Environmental Quality has already received some 2,500. It is not meant to imply that existing mechanisms should be weakened or transferred.

It is recognized also that bills to establish a congressional Office of Technology Assessment have been offered in recent sessions, and we believe this to be a step in the right direction.[8]

Recommendation V is offered with full realization of existing and pending efforts. But two points may be emphasized that have been made in recent study reports on technology assessment.[9] The first is that we must begin immediately to define and refine the techniques and methodology of the assessment process. The second is that the scope of the need is so vast that nothing less than a major commitment will suffice.

The burden of decision on technological issues in public affairs falls squarely upon the shoulders of our elected representatives. Government will undoubtedly be inundated with enthusiastic requests for support of new technologies and with predictions of peril from equally convincing experts. Attempts to compute social benefits and social costs may yield only rough approximations. Choices among options will be difficult, decisions will be controversial. Although those charged with governance are accustomed

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[8] Legislative Report No. 92-469, *Establishing the Office of Technology Assessment and Amending the NSF Act of 1950.* U.S. House of Representatives, Committee on Science and Astronautics, 92nd Congress, 1st Session.

[9] *Technology: Processes of Assessment and Choice*, National Academy of Sciences, July 1969; *A Study of Technology Assessment*, National Academy of Engineering, July 1969; *A Technology Assessment System for the Executive Branch*, National Academy of Public Administration, July 1970.

to being the focal point of such debate, they will have an increasing need for professional and technical advice. The distinction between tentative technical judgment and established fact can be very subtle, requiring cross-examination by highly skilled experts. Thus, officials will require more and more professional assistance to assess the assessors.

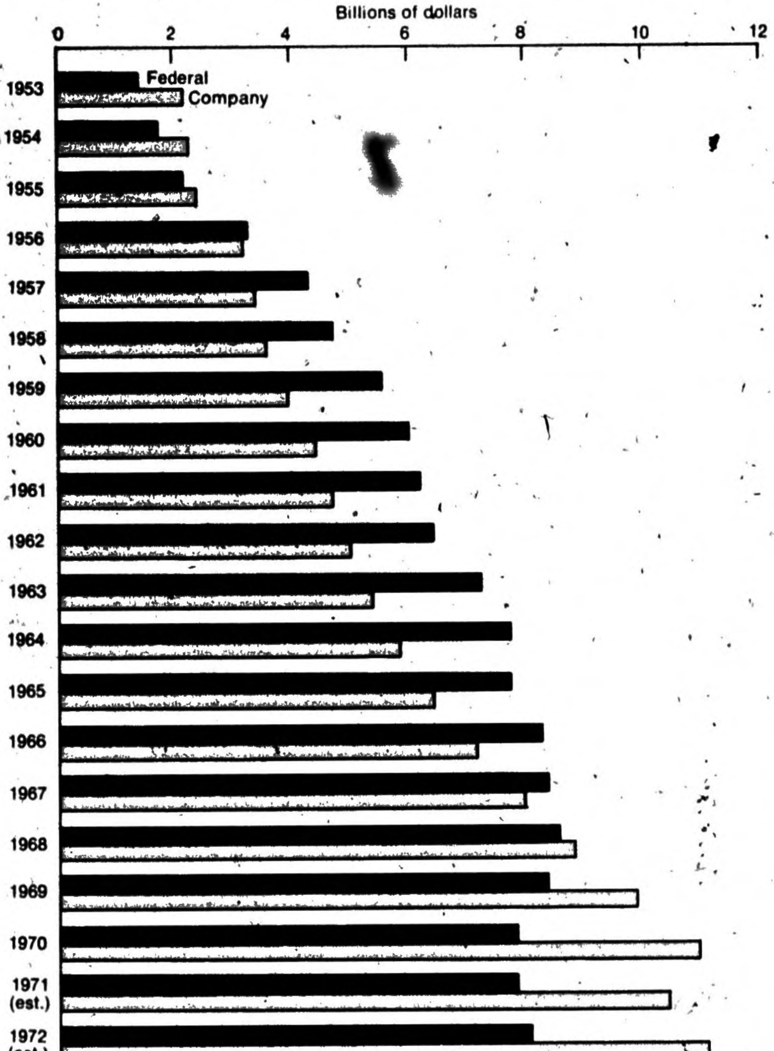
It may be pointed out that there already exists a large and complex "machinery of advice," including scientific and engineering advice, in the Federal Government. It works through literally hundreds of technical committees, contributions by specialist consultants, and *ad hoc* technical studies. Until recently, this machinery addressed itself chiefly to relatively narrow, highly specific, subjects — technical issues related to coal mine safety, for example, or isolated issues within the technology of nuclear reactors. Lately, there has been some broadening. The point is, the existence of this machinery establishes the principle that such advice is wanted and used in Government.

But we believe that the participation of engineers and scientists should be formalized, that their professional thinking and judgments should enter into deliberations on the broadest questions presenting technical issues *at the very beginning*; that the numbers participating should be increased to the levels needed at the various points of policy making and decision making where they are assigned; that their participation should be full time in a greater number of instances; and that the places where they are needed should be carefully identified. In fact, an adequate "in-house" capability is essential to make use of and couple the judgments of outside advisory groups to decision-making. It is desirable that the Legislative Branch be strengthened in this respect, to reinforce its coordinate and equal role in our system.

CONCLUSION

This Report, while recognizing the problems facing technology in this country today, has sought to concentrate on positive steps by which the great capabilities of American science and engineering may be helped to attain their fullest effectiveness in meeting national needs. Progress on that path can bring strengthening of the industrial base of our economy, reinforce the domestic and international economic position of the United States, and provide direct assistance toward the solution of major societal problems and enhancement generally of the quality of life. These are the purposes of the technologies of peace, the employment of the discoveries of science in the service of man. Their achievement is within our power.

Federal and company share of industrial R&D spending, 1953-1972



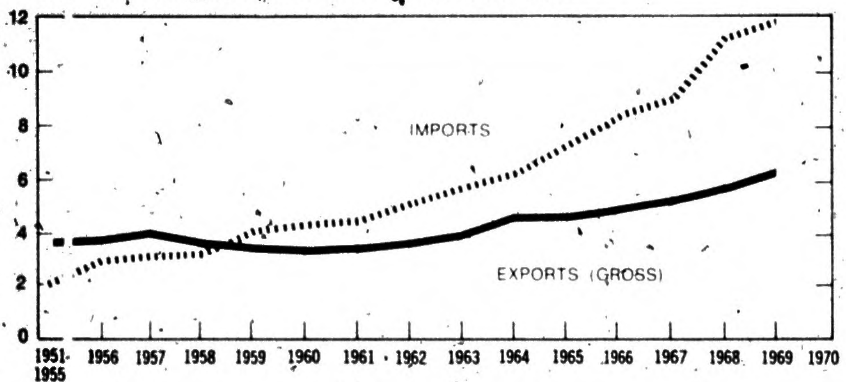
Excerpt from Research and Development in Industry, 1969—Surveys of Science Resources Studies, National Science Foundation—April 1971 (NSF 71-18)

SOURCE: National Science Foundation

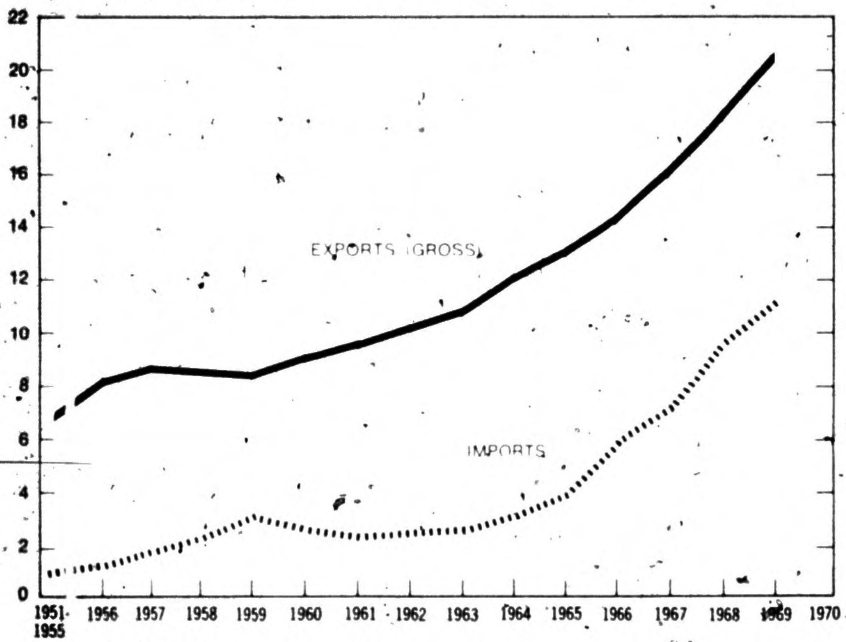
APPENDIX B

Trends in U.S. trade

Not "Technology-Intensive" Manufactured Products



"Technology-Intensive" Manufactured Products



Excerpt from Technology and International Trade, Proceedings of the Symposium Sponsored by the National Academy of Engineering at the Sixth Autumn Meeting—October 14 and 15, 1970.

APPENDIX C

Some important inventive contributions of independent inventors and small organizations in the twentieth century

Xerography
Chester Carlson

DDT
J. R. Geigy & Co.

Insulin
Frederick Banting

Vacuum Tube
Lee De Forest

Rockets
Robert Goddard

Streptomycin
Selman Waksman

Penicillin
Alexander Fleming

Titanium
W. J. Kr[illegible]

Shell Molding
Johannes C[illegible]

Cyclotron
Ernest O. Lawrence

Cotton Picker
John & Mack Rust

Shrink-proof Knitted Wear
Richard Walton

Dacron Polyester Fiber "Terylene"
J. R. Whinfield, J. T. Dickson

Catalytic Cracking of Petroleum
Eugene Houdry

Zipper
Whitcomb Judson, [illegible] Sundback

Automatic Transmissions
H. F. Hobbs

Gyrocompass
A. Kaempfe, E. A. Sperry, S. [illegible] Brown

Jet Engine
Frank Whittle, Hans V[illegible]

Frequency Modulation Radio
Edwin Armstrong

Self-Winding Wristwatch
[illegible] Harwood

Continuous Hot-Strip Rolling of Steel
John B. Tytus

Helicopter
[illegible]

Mercury Dry Cell
Samuel Ruben

Power Steering
Francis Davis

Kodachrome
L. Mannes & L. Godowsky Jr.

Air Conditioning
Willis Carrier

Polaroid Camera
Edwin Land

Heterodyne Radio
Reginald Fessenden

Ball-Point Pen
Ladislao & Georg Biro

Cellophane
Jacques Brandenberger

Tungsten Carbide
Karl Schroeter

Bakelite
Leo Baekeland

Oxygen Steelmaking Process
C. V. Schwartz, J. Miles, R. Durrer

[illegible] Management
Department [illegible]

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